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GEOLOGIC RECONNAISSANCE IN BAJA CALIFORNIA

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During 1921, I spent several months in Baja California determining geologic relations of a large area, and as there is but little on record regarding the geology of this region, it is desirable to set forth such of my observations as appear to be of general interest. I journeyed with pack train from near Ensenada southward to beyond Comondu and later extended the reconnaissance to beyond La Paz as far as Todos Santos. Most of the observations were in the district between the high sierra and the west coast, but the peninsula was cross-sectioned near San Ignacio and Santa Rosalia, from Mulegé to La Purisima, and in the La Paz region (Fig. 1).

Most of my attention was given to the sedimentary rocks of Cretaceous and Tertiary age, but the limits and character of some of the crystalline rocks were ascertained. Many of the general relations are set forth in the cross-sections of Figures 2, 3, and 4.

PRE-CRETACEOUS

The lowest strata observed were schists and other metamorphic rocks, invaded by white, massive, coarse-grained granite. At most places this granite includes fragments of schist, and many clearly intrusive contacts were noted. The granite constitutes the high Sierra San Pedro Martir in the north central part of the peninsula, where one or two summits reach an altitude of about 10,000 feet. It also outcrops north of Ensenada, north of Santa Caterina, and in many high central ridges from latitude 29° 30′ to latitude 28°, and is prominent in the sierra at the lower end of the peninsula southeast of La Paz. I crossed the schists in several broad zones between Santa Caterina and Calmalli and noticed that a few miles

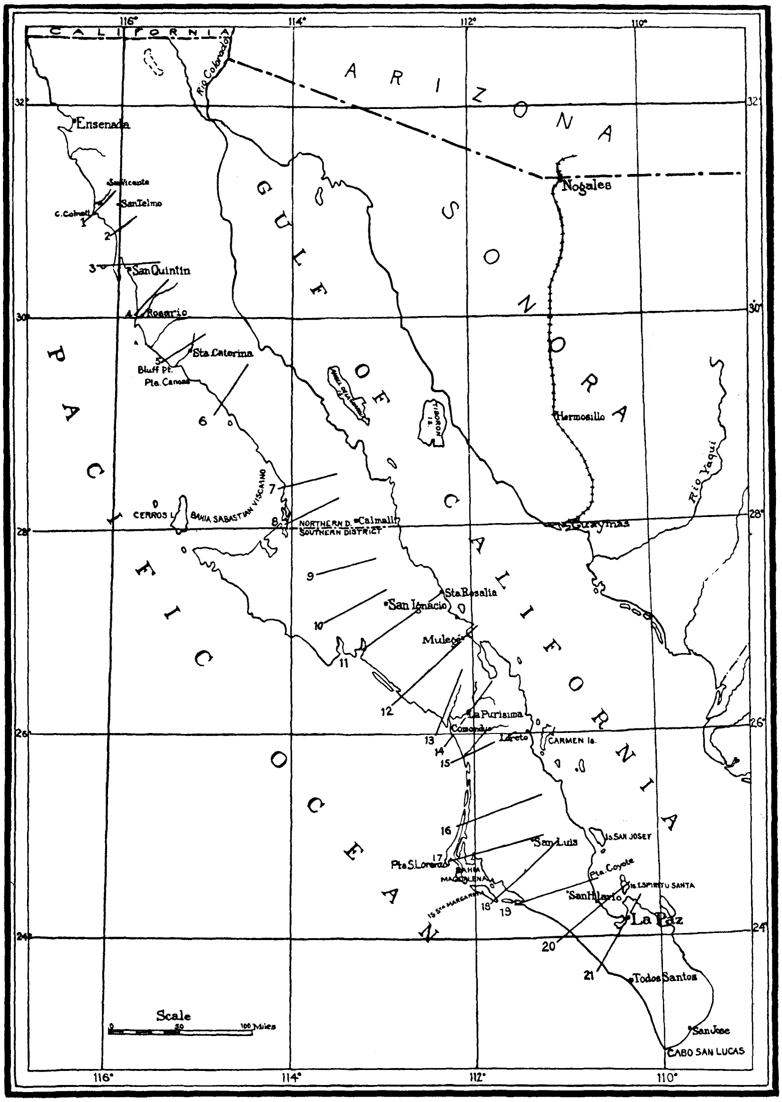

FIG. 1.—Map of Baja California showing principal shore features and settlements, and location of cross-sections in Figures 2, 3, and 4.

south of the latter place they are overlapped by younger sediments. They appear again in high ridges in Cerros Island and from Punta San Lorenzo to Isla Santa Margarita on the west side of Bahia

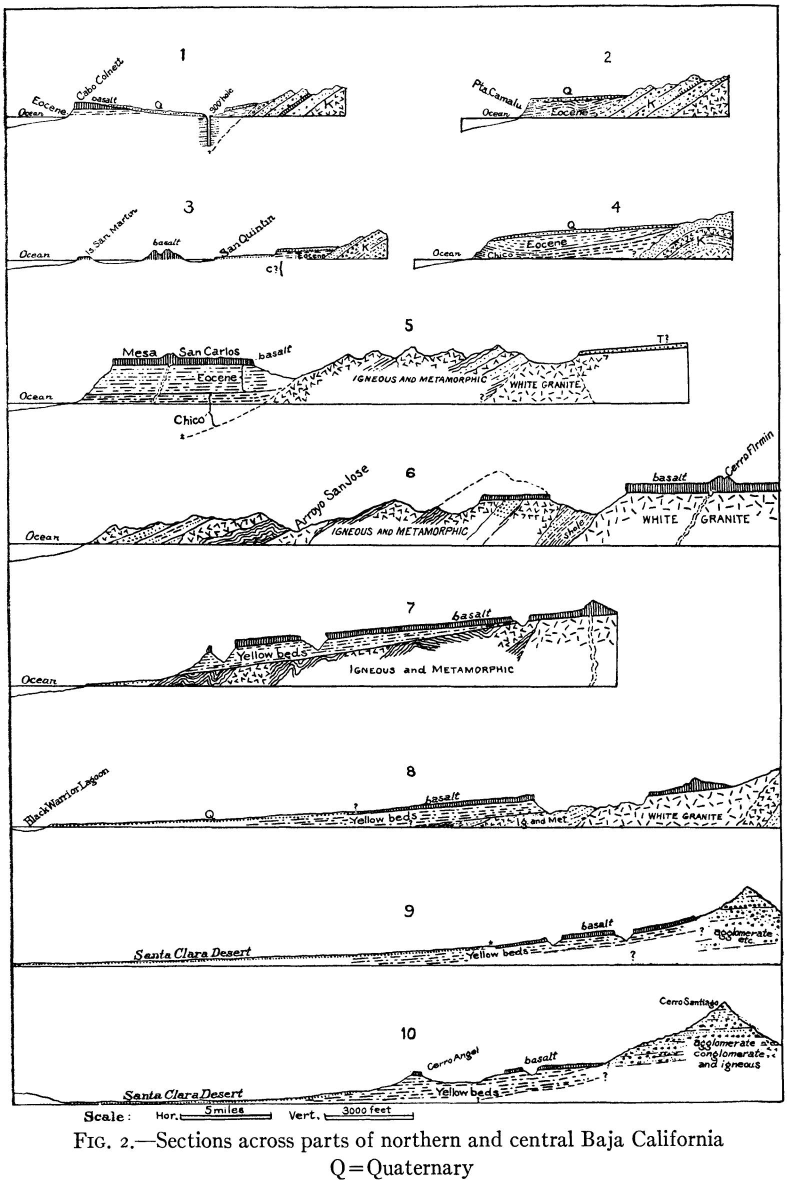

FIG. 2.—Sections across parts of northern and central Baja California
Q=Quaternary

de la Magdalena.[1] They also occur in the south end of the peninsula in the Triunfo mining district south of La Paz.

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[1] According to J. Ross Brown, *Resources of the Pacific Slope*, San Francisco, 1869, p. 143.

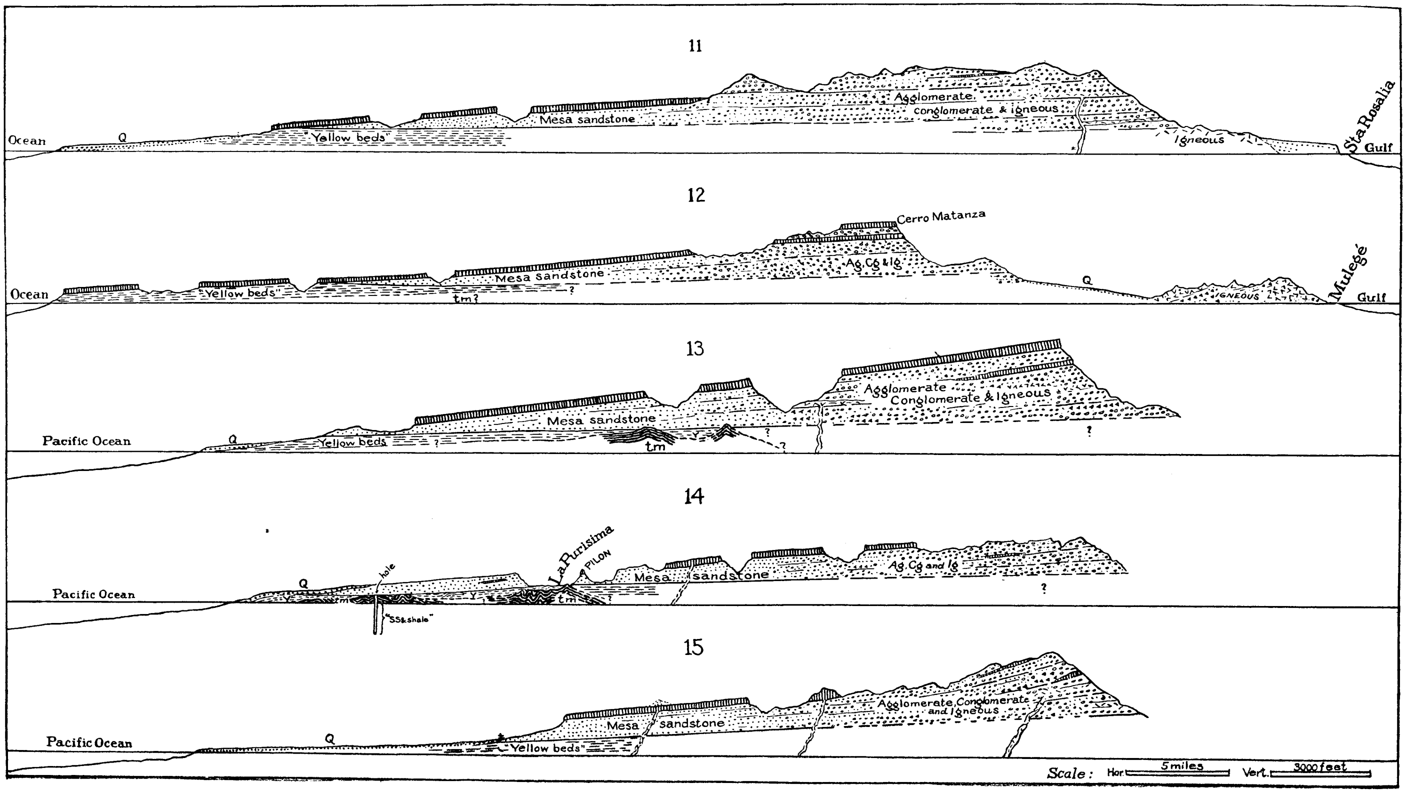

Fig. 3.—Sections across central Baja California
Q=Quaternary

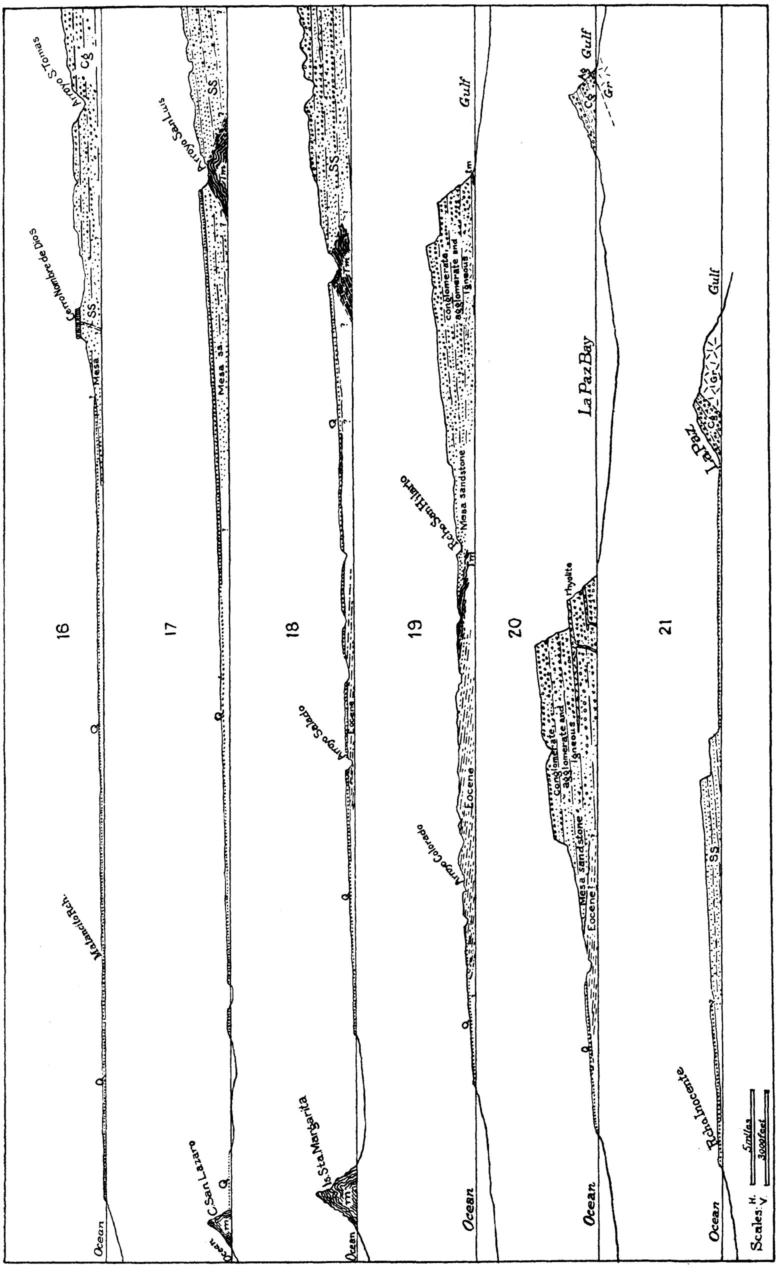

FIG. 4.—Sections across part of southern Baja California

Lindgren[1] has given considerable information regarding schist and granite in the northern part of the peninsula; Gabb[2] noted some features observed on his trip north from La Paz; and Emmons and Merrill[3] described relations of the schists near the onyx quarries east of Santa Caterina.

I obtained no evidence as to the age of these granites and schists, but my general impression was that they were much older than Cretaceous. I did not observe any overlap by Cretaceous rocks, but I saw Tertiary deposits lying on or against them at various places. In the region east of La Paz, the granite appears to be the floor on which the Tertiary volcanic series lies. This relation is strongly indicated at Cabo Lobos on the east side of Isla Espiritu Santo where a separating fault appears hardly possible. A similar relation is indicated in Sierra Giganta, northwest of Loreto. The structural relations of the ridges of schists in Isla Santa Margarita and extending northward to Cabo San Lazaro is not known, and it is not unlikely that these rocks are the uplifted floor of the strata farther east.

CRETACEOUS SYSTEM

General relations.—A large part of the peninsula is underlain by Cretaceous rocks which outcrop extensively in the central and northern parts. Two principal series are present, both of late Cretaceous age and separated by an uncomformity, the older series, of unknown correlation, having been uplifted, flexed, and cut by large igneous masses before the younger series, Chico, was deposited. The Chico beds were not observed in contact with the older series, and the principal evidence of the separateness of the two is the difference in attitude of the beds throughout the area and the fact that the older series is uncomformably overlapped by the Eocene strata which lie with apparent conformity on the Chico beds. This relation is shown in the following section (Fig. 5).

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[1] Lindgren, "Notes on the Geology of Baja California, Mexico," *Proc. Cal. Acad. Sci.*, Second Series, Vol. I (1889), pp. 173–96, and Vol. II (1890), pp. 1–17; and "Geology and Petrography of Baja California, Mexico," *Proc. Cal. Acad. Sci.*, Second Series, Vol. III (1890), p. 26.

[2] W. B. Gabb, *Geol. Survey of Cal.: Reports*, Vol II (1869), Appendix, pp. 1–20.

[3] S. F. Emmons and G. P. Merrill, "Geological Sketch of Lower California," *Bull. Geol. Soc. Am.*, Vol. V (1894), pp. 489–514.

These pre-Chico Cretaceous rocks consist of conglomerates, quartzites, tuffs, and agglomerates with large bodies of interbedded eruptive rocks. They are also cut by dikes and large stocks of igneous rocks of various kinds. In many localities theigneous rocks predominate over the sediments or pyroclastics, and in places there is much metamorphism. Unaltered or but little altered sandstone and shales appear in places, notably near old San Domingo Mission, 25 miles north of San Quintin, where they contain many large oyster shells, and in the Arroyo San José, 40 miles southeast of Santa Caterina. Limestone also occurs. It is conspicuous north and northeast of the ruins of Mission San Fernando, 30 miles due east of Rosario, where the relations shown in the following sketch section (Fig. 6) are presented. The limestone is filled with fossil oysters of upper Cretaceous age. Part of the outcrop is shown in Figure 7.

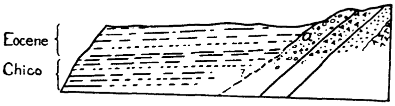

FIG. 5.—Sketch section showing relations of Eocene and Chico beds to metamorphic and igneous rocks of Cretaceous (pre-Chico) age, near latitude 30°, west coast, Baja California. *a*, exposed overlap of Eocene beds.

These metamorphic Cretaceous rocks appear to extend as far south as latitude 28° 40′, and possibly the schists and other rocks, although apparently of an older series and extending to Calmalli, may be metamorphosed Cretaceous sediments. Apparently they are so regarded by Bosé and Wittish in their brief statements regarding relations in the Northern District.[1]

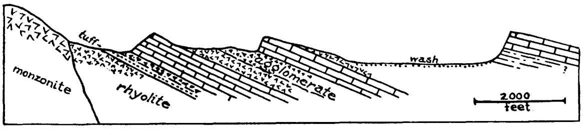

FIG. 6.—Sketch section showing relations of Cretaceous limestone north of the ruins of San Fernando Mission, 30 miles east of Rosario, Baja California.

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[1] "Memoria de la Comisión del Instituto Geológico de México que exploró la región Norte de la Baja California," *Inst. Geol. de México, Perergones*, Vol. XIV (1913), pp. 307–533.

CHICO FORMATION

The upper part of the Chico formation (late Cretaceous) rises above sea-level a few miles north of Rosario, and it remains in view along the ocean bluffs and lower parts of the valleys of the Rio Rosario, Arroyo San Vicente, Rio San Fernando, and Arroyo Santa Caterina as far as latitude 29° 24′, a few miles southeast of Punta Canoas. The rocks are soft sandstone and shale of light-gray to buff color with round concretions at most places. Emmons and Merrill[1] noted the occurrence of Upper Cretaceous fossils at a point about 3 miles north of Santa Caterina Landing. Specimens collected from massive sandstone near sea-level and in calcareous layers 200 feet above were determined by T. W. Stanton as follows: *Arca breweriana* Gabb; *Baculites chicoensis* Trask; *Tessarolax distorta* Gabb; and *Inocerami*, not determinable.

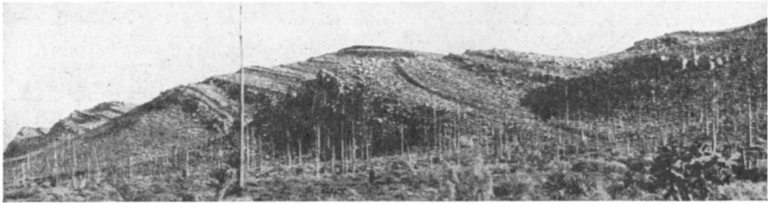

FIG. 7.—Fossiliferous Cretaceous sandstone northeast of San Fernando Mission, twenty miles east of San Rosario, Baja California.

The fossils which I obtained in these beds at the Arroyo Hondo, 15 miles north of Rosario, were identified by Dr. T. W. Stanton as follows: *Ryhnchonella* sp.; *Ostrea* sp.; *Inoceramus whitneyi* Gabb; *Yoldia nasuta; Nemodon vancouverensis* Meek?; *Dentalium* sp.; *Gyrodes* sp.: *Anchura* sp.: *Cinulia obliqua* Gabb; *Baculites chicoensis* Trask; and *Baculites occidentalis* Meek. All these fossils are typical of the Pacific Coast Chico which is of Upper Cretaceous age.

Lindgren[2] has reported the occurrence of the Chico fossil, *Coralliochama orcutti*, in sandstones appearing in a small area among the volcanic rocks a few miles southwest of Ensenada.

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[1] *Op. cit.*, p. 501.

[2] *Op. cit.*, p. 176.

TERTIARY SYSTEM

EOCENE

General relations.—I found that on the shore of the Pacific Ocean the earlier Tertiary deposits began at the mouth of the Rio San Vicente in latitude 31° 30′ and extended south to about latitude 29° 25′, south of Punta Canoas. In this area they underlie a narrow coastal plain mostly from 8 to 10 miles wide, but broadening to nearly 20 miles near latitude 30°. They lie on the Chico beds but to the east abut against the metamorphic pre-Chico rocks, and the termination of the crop to the north and south is due to the westward extension of the latter to the ocean shore. Throughout the area the strata dip at very low angles to the west, and local flexures are rare and slight. Some general relations are shown in sections 1–5, Figure 2.

The rocks are shales and sandstones mostly of light-gray to buff color, 1,200 feet or more thick near latitude 30°. To the south they contain fossils of the Martinez or Middle to Lower Eocene age, but in the region north of latitude 30° most if not all of the beds appear to be Tejon or Upper Eocene, although the lower formations may exist beneath the surface. There are prominent exposures along the lower parts of the valleys of the Rio Rosario, Arroyo San Vicente, Rio San Fernando, and Arroyo Santa Caterina, near Rosario and southward, and in bluffs along the ocean near Cabo Colnett and Punta Camalu and near Bluff Point and Punta Canoas, the two latter southwest of Santa Caterina. As shown in section 5, Figure 2, the thick succession of beds exposed in the bluffs along the ocean at Bluff Point is preserved by the heavy lava cap of Mesa San Carlos.

Fossils.—Fossils were collected at several localitities in the Eocene beds and kindly determined for me by Dr. Julia A. Gardner. On the shore of the Pacific Ocean, a mile south of the mouth of the Arroyo San Antonio, latitude 31° 05′, the following were found: *Cylichna* sp.; *Turritella* n.sp., cf. *T. uvasana* Conrad; *Amauropsis* sp.; *Leda* sp.; *Cucullaea matthewsoni*, Gabb?; *Cardium*, cf. *C. breweri* Gabb; *Cardium* sp.; *Tellina?* sp.; and *Semele* sp.

On the ocean shore a half-mile south of Colnett Creek, 5 miles southeast of Cabo Colnett, were collected *Omphalius* sp.; *Cardium* n.sp., cf. *C. quadrigenarium* Conrad. In the bluffs 5 miles east of San Quintin there were collected *Turritella* n.sp.: *Leda* sp.; *Tellina* sp., cf. *T. hornii* Gabb; and *Spisula* sp., cf. *S. merriami* Gabb. In the drift at the mouth of San Simon Cañon, 6 miles southeast of San Quintin, *Cardium cooperi* Gabb? was collected. These are all regarded as Tejon or Upper Eocene in age. The following fossils were collected from two horizons in the slopes about 5 miles northeast of Santa Caterina Landing: Upper beds, *Surcula* sp.; *Heterotoma gabbi* Stanton: *Turritella pacheococensis* Stanton?; *Turritella* sp.; *Natica (gyrodes)*, cf. *N. lineata* Dickerson; *Amauropsis* sp.; *Dentalium cooperi* Gabb?; *Leda* sp. 2; *Glycimeris* n.sp. aff. *G. veatchii* var. *major* Stanton; *Cucullaea matthewsoni* Gabb; *Ostrea* sp. ind.; *Pecten* sp.; *Pinna* sp.; *Crassitellites* sp.?; *Venericardia planicosta* Lamarck var.; *Phacoides* sp., cf. *P. diegoensis* (Dickerson); *Phacoides* sp.; *Cardium cooperi* Gabb?; *Cytherea* sp. aff. *C. hornii* Gabb; *Spisula* sp. The age of these is regarded as Upper Martinez or Middle Eocene.

From beds 200 feet lower were collected: *Cucullaea matthewsoni* Gabb?; *Ostrea* sp. ind.; *Anomia* sp.; *Lima multiradiata* Gabb; *Phacoides* sp. ind. The age of these is regarded as Lower or Middle Martinez or Lower Eocene.

Emmons and Merrill[1] reported fossils from rolled pebbles of impure limestone obtained along the beach of the south of Santa Caterina Landing "which had evidently fallen from the cliffs above, and from a bed of similar composition in place at what was assumed to be about 1,200 feet higher in horizon, at San Carlos anchorage (collected by Mr. A. E. Foote), 8 miles north of Bluff Point." These were determined by Dr. T. W. Stanton as follows: *Cardita planicostata* Lam., *Leda gabbi* Conrad, *Urosyca caudita* Gabb, and undetermined species of *Nucula*, *Pectunculus*, *Tellina*, *Turritella*, *Dentalium*, and *Crassatella*. These forms were regarded as Tejon (Upper Eocene).

EOCENE (?) WEST OF LA PAZ

Sandstones which appear to be of Eocene age outcrop in an oval area of about 200 square miles in the valleys of arroyos Liebres, Colorado, San Hilario, and Guadalupe, all west of San Hilario.

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[1] *Op. cit.*, pp. 501–2.

Smaller exposures are revealed by the Arroyo Salado and its branches near Rancho Sauce, 35 miles west-northwest of San Hilario, and by arroyos Conejo and Datilari, 20 miles south-southeast of San Hilario (or about 40 miles due west of La Paz).

The rocks are light-gray sandstone, mostly soft, but with harder layers and hard concretions. Some argillaceous members are included and some of the sandstone layers have a greenish tint. In the extensive exposures on the Arroyo Colorado about Rancho Tepetate where dips are from 3° to 5°, the thickness is not less than 3,000 feet unless the strata are duplicated by faulting. The dips are somewhat steeper near Rancho Sauce where more than 2,000 feet of beds are exposed. One of the largest outcrops in this vicinity is just south of Rancho Santa Rosa where sandstone ledges extend along the banks of the arroyo for several miles. It is capped by late Tertiary or Quarternary conglomerate and limestone. In the valley of the Arroyo de los Liebres, ledges of sandstone and sandy clays are exposed in a wide area of low ledges and buttes which extend to, or nearly to, the mouth of the arroyo. All the dips are at low angles to the north.

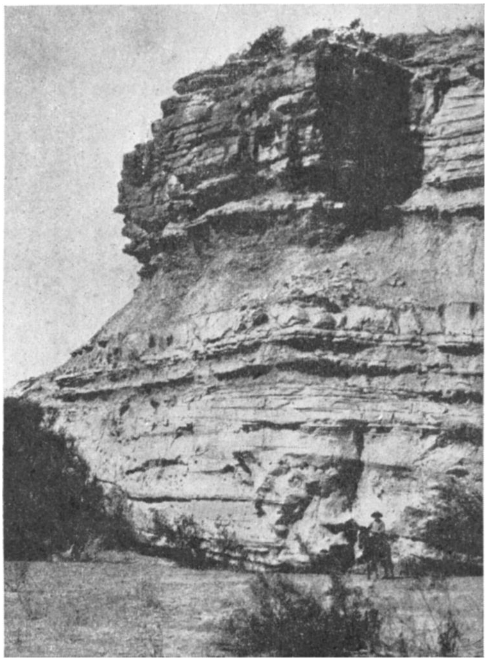

FIG. 8.—Sandstone (Eocene?) on the Arroyo Colorado one mile below Rancho Tepetate, ten miles west of San Hilario, Baja California.

The exposures in the valley of the Arroyo Colorado extend from the junction with the Arroyo de los Liebres nearly to the mouth of the Arroyo Caracol. Prominent cliffs of the sandstone occur at

Rancho Tepetate and for some distance above and below that place (Fig. 8). Dips are all to the north or north-northeast at low angles. The outcrop of the formation extends up the Arroyo San Hilario to within about 4 miles of Rancho San Hilario where the top member is massive, pale buff sandstone with irony layers and many fragments of oyster shells. It dips north and apparently passes beneath the Monterey beds. There sandstones have yielded few fossils, but echinoid spines and foraminifera are abundant at Rancho Tepetate, and oysters and a shark's tooth near Rancho Santa Teresa all appear to indicate Eocene age. Evidently the exposures are due to a mound of the formation extending southeast and southwest with altitude sufficiently great in the region from the Arroyo Salado to the Arroyo Conejo for the strata to be revealed by erosion in the deeper valleys.

MIOCENE

Monterey beds.—In the vicinity of the oases of La Purisima and San Hilario I found small exposures of strata so closely resembling the Monterey formation of southern California that tentative correlation seems desirable. Outcrops extend along the Arroyo de la Purisima from 2 miles above tidewater to within 6 miles of La Purisima and a small one appears in the upper part of the latter village. Outcrops also extend along the valley of the Arroyo San Gregorio for a mile or more about 10 miles southwest of La Purisima, and smaller crops appear above Purisima Vieja and San José, respectively 15 and 20 miles northwest of La Purisima, and on the Arroyo San Raimondi, 35 miles northwest of La Purisima. The same beds appear in an area of 2 or 3 square miles a short distance west of San Hilario, and in small crops of steeply upturned beds appearing at intervals from a point a mile northwest of San Luis to a point 15 miles southeast of that place. The relations are shown in sections 13, 14, 17, 18, and 19, Figures 3 and 4. At most places the beds are more or less tilted and flexed, and various younger formations overlie them unconformably, as shown in Figures 9 and 10, although at several places where the strata are not flexed there appears to be gradation into the overlying "yellow beds."

The principal rocks of the Monterey beds are gray to pale-buff, fine-grained sandstone and sandy shale with abundant fish scales. They include interbedded diatomaceous deposits mostly from 1 to 3 feet thick and some thin layers of glassy silica from buff to black in color. More than 500 feet of beds are exposed along the Arroyo de la Purisima where for several miles the formation extends from 5 to 20 feet above the bed of the arroyo and there are many flexures.

The southernmost exposures in the Arroyo de la Purisima in the west end of the Big Bend about 2 miles above tidewater contain much fine, white diatomaceous earth interbedded in fine-grained, yellowish sandstone and compact shale with many fish scales. In this region the dips are to the west or southwest, so that higher beds rise as the valley is ascended. In about 3 miles the lowermost beds appear in the crest of a low anticline, and from these were obtained the following fossils, determined by Dr. Julia A. Gardner: *Scutella andersoni; Chrysodomus* sp.; *Turritella* sp., cf. *T. margaritana* Normand; *Vermetus* sp.; *Leda* sp.; *Arca*, cf. *A. medioimpressa* Clark; *Pecten*, cf. *P. crassicardo* Conrad; *Crassitellites* (*Crassinella*) sp.; *Cardium* sp. nov.; *Chione* sp.; *Cytherea* sp.; *Mecoma* sp.; *Solen* sp.; and some corals and bryozoa. The age is regarded as probably Vaqueros, equivalent to Lower Monterey. These lowest beds appear again in another small uplift a short distance north, beyond which the strata descend in apparent regular order showing extensive exposures in the banks of the arroyo as shown in Figure 9. Here the formation is overlain by conglomerate.

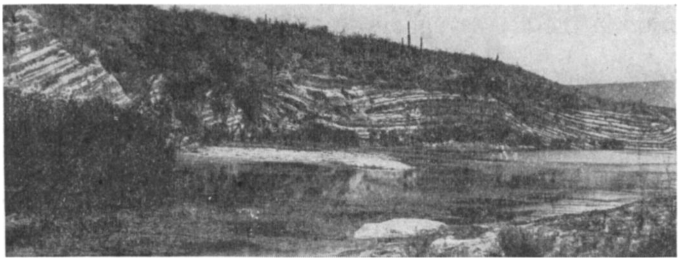

FIG. 9.—Flexures in the Monterey beds on the Arroyo de la Purisima, ten miles below La Purisima, Baja California.

Yellow beds.—Under this title I shall group deposits of late Miocene age exposed extensively along the western slope of the peninsula from latitude 29° to latitude 24°. They are mostly soft, loamy sandstone and sandy clay of pale straw-yellow tint with local limy beds, the latter generally full of fossils. Some contemporaneous igneous rocks are included in places. The yellow beds have an aggregate thickness of 500 feet near the coast between San Ignacio and La Purisima, although at the latter place the amount is not more than 120 feet. As stated above, there is unconformity between this formation and the Monterey beds, only noticeable, however, where the latter are flexed; the overlying "mesa sandstone" is also unconformable, as shown in Figures 11 and 12.

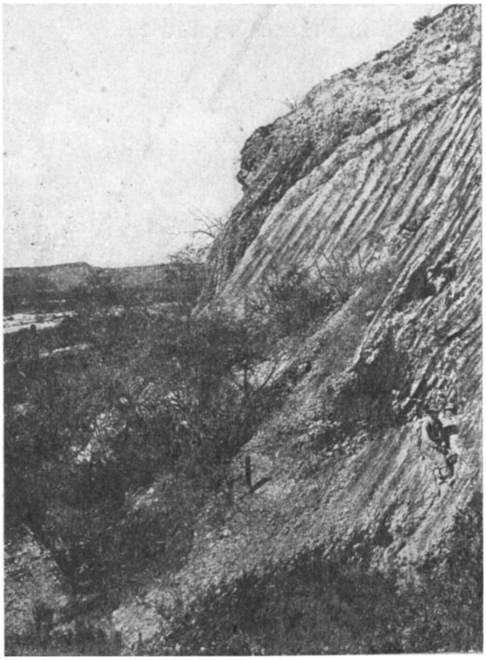

FIG. 10.—Steeply tilted Monterey beds on east side of the Arroyo de la Purisima, six miles below La Purisima, Baja California.

The yellow beds are first noticeable in thin, scattered bodies lying on the metamorphic series near latitude 29°. Near latitude 28° 30′ they have the relations shown in section 7, Figure 2, having been preserved from erosion by a thick cap of basalt. This relation continues for many miles south, as shown in sections 8–15, although the floor of metamorphic rocks sinks out of sight a short distance south of Calmalli. In the La Purisima region and near San Hilario the underlying formation is the rather uneven surface of the Monterey beds. Probably the formation thickens considerably under the Santa Clara Desert, where doubtless it is underlain by later Cretaceous rocks such as those reported to appear in the southern portion of the Santa Clara Mountains.

Local features.—About 150 feet of the yellow beds are exposed under the lava cap at Cerro Angel, 17 miles west of San Ignacio (see sec. 10, Fig. 2). The principal material is gray to pale greenish-yellow sandstone with beds of volcanic ash. There are extensive exposures about San Ignacio where the strata are capped by basalt, as shown in Figures 13 and 14.

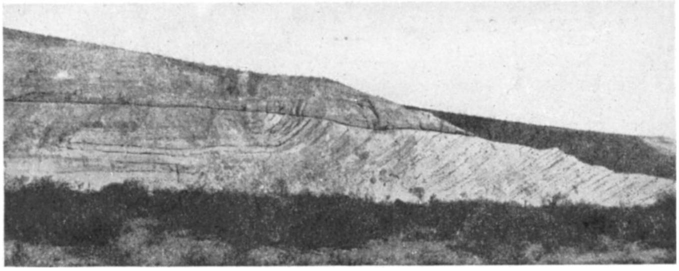

FIG. 11.—Upturned "yellow beds" overlain unconformably by Mesa sandstone, six miles west of La Purisima, Baja California.

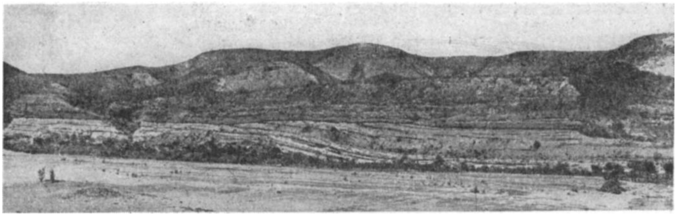

FIG. 12.—"Yellow beds" overlain unconformably by Mesa sandstone on Arroyo de la Purisima, five miles below La Purisima, Baja California.

The yellow beds in the exposures extending from the Arroyo Valle to beyond Rancho Quarente, about 40 miles south of San Ignacio, present a uniform succession, about 500 feet thick, of soft, yellowish sandstone and loam. The base is not exposed and the top is eroded. Some beds contain considerable clay, and others are nearly pure sand. The principal color is a pale greenish-yellow. A few thin layers of hard sandstone and conglomerate are included. A hard fossiliferous layer occurs in places in the middle of the beds exposed.

The yellow beds outcrop for many miles along the Arroyo San Raimondi (or San Miguel), 30 miles northwest of La Purisima, from a point a half-mile above Rancho las Tules to its mouth, with relations shown in Figure 16. Pale-yellow, loamy sands or soft sandstone prevail, and at several points, notably at Rancho San Antonio and near the outcrop of the Monetrey beds 6 miles southwest of Caije (a very small settlement 35 miles northwest of La Purisima), a basal limestone member is exposed filled with fossils (not determined). Agglomerate and sheets of lava occur in the lower part of the formation in this valley, as shown in Figure 16.

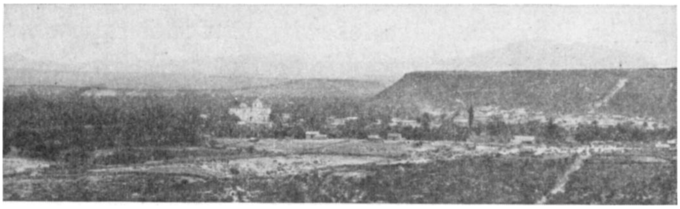

FIG. 13.—San Ignacio, Baja California, from the south. High sierra in distance; later Miocene capped by basalt in middle distance.

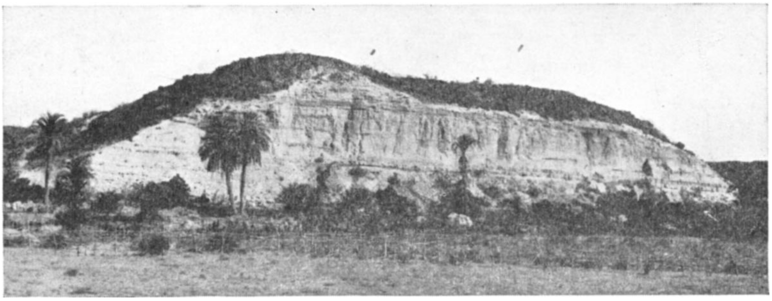

FIG. 14.—Upper Miocene strata capped by basalt at San Ignacio, Baja California

In the valleys of the Arroyo Juanico and the Arroyo Mesquital, 20 to 25 miles west of La Purisima, the yellow beds are exposed in slopes and cliffs of considerable extent, overlain in part by lava and to the east by gravell beds at the base of the mesa sandstone. The principal material is soft, yellowish sandstone, in part containing some clay. The top beds have been eroded and the base is not revealed, although probably not far below the bottom of the valleys.

In the Arroyo San Gregorio, about 6 miles southwest of La Purisima, the yellow beds are exposed lying on Monterey beds and overlain by mesa sandstone. They thin rapidly to the north where the surface of the Monterey beds rises rapidly. The yellow beds outcrop prominently again near Purisima Vieja, 10 miles northwest of La Purisima, exhibiting all the strata down to the richly fossiliferous limestone bed which occurs at the base of the formation near La Purisima. The following section is exposed in this vicinity. Probably Monterey beds are not far below the bottom of the arroyo at this place.

The stratigraphic relations of the yellow beds are extensively exposed in the Arroyo de la Purisima from near its mouth to a point about 6 miles above La Purisima where the base of the overlying mesa sandstone crosses the canyon. The principal features are shown in the cross-section 14, Figure 2, and the columnar sections in Figure 17. For some distance near the 1,360-foot boring the yellow beds may either thin out or give place horizontally to a massive bed of conglomerate which lies on the Monterey beds; the precise relations are obscured by talus which breaks the continuity of the outcrops. The view, Figure 18, shows high cliffs 10 miles below La Purisima where the yellow beds include a massive member of impure limestone filled with fossils, apparently the same bed as the first one rising above tidewater several miles southwest (see Fig. 17, sec.1). This bed appears either to thin out or to give place to sandstone and agglomerate farther north near the drill hole. There are extensive exposures of yellow beds about La Purisima (see Fig. 19) with a basal member of limestone filled with

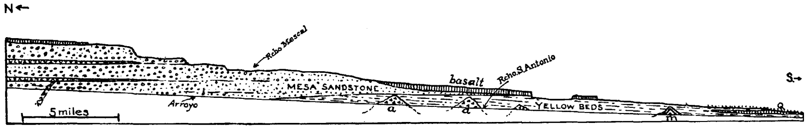

FIG. 15.—Section in the Arroyo San Raimondi northwest of La Purisima, Baja California. *a*, agglomerate; *m*, Monterey beds; *q*, Quaternary.

fossils. This member is conspicuous in the bed of the arroyo a short distance below the village where it is crumpled in a series of small but closely appressed flexures. It also outcrops almost continously for several miles below this place, mostly in the bed of the arroyo. At two localities about 4 miles below La Purisima, small arches reveal the top of the underlying Monterey beds with contact clearly exposed. The yellow beds and this basal limestone disappear a short distance farther downstream or near the 1,360-foot boring, as shown in Figure 17. The precise stratigraphic conditions at this place could not be ascertained, but the basal limestone, at least, appears to abut against the old slope of a mound of Monterey beds, probably a local shore line.

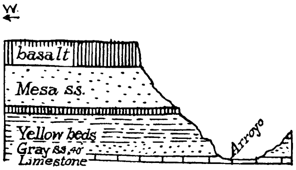

FIG. 16.—Section on the west side of the Arroyo San Gregorio opposite Purisima Vieja, ten miles northwest of La Purisima, Baja California, looking north.

The igneous rocks included in the yellow beds are the products of contemporaneous volcanic action, and it is not unlikely that to the east they grade into the lower part of the great succession of agglomerates, etc., which constitute the base of the high sierra. In the valley of the Arroyo San Raimondi (or San Miguel), 40 miles northwest of La Purisima, there are many exposures of large bodies of agglomerate included in or displacing the upper members of the yellow beds (see Fig. 20). One notable outcrop is near the Rancho San Antonio, where the rocks have the relations shown in

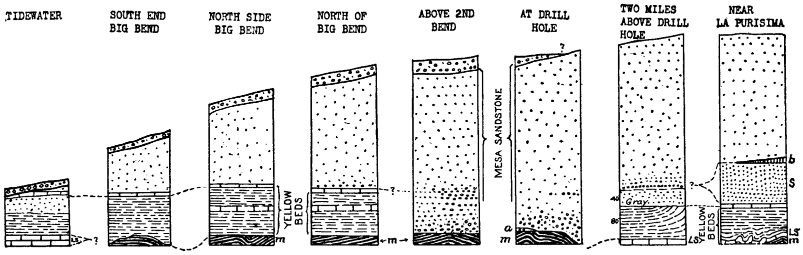

FIG. 17.—Columnar sections along the Arroyo de la Purisima, showing the stratigraphical relations of the yellow beds. *m*, Monterey beds; *a*, agglomerate; *ls*, fossiliferous limestone at base of yellow beds; *s*, massive sandstone at La Purisima; *b*, sheet of basalt in mesa sandstone.

Figure 15. Another similar mass is exposed in the Arroyo Valle, 8 miles west of Rancho San Antonio, and on the Arroyo Vaca, 50 miles west by north of La Purisima, there is an exposure high in the canyon walls showing the relations indicated in Figure 21. This section shows that the agglomerate was erupted during the time of deposition of the yellow beds and prior to the lava flow which now caps the mesas. A small amount of agglomerate lies on the Monterey beds in the Arroyo San Gregorio, 11 miles W. 10° S. of La Purisima, and also near the 1,360-foot bore hole on the Arroyo de la Purisima.

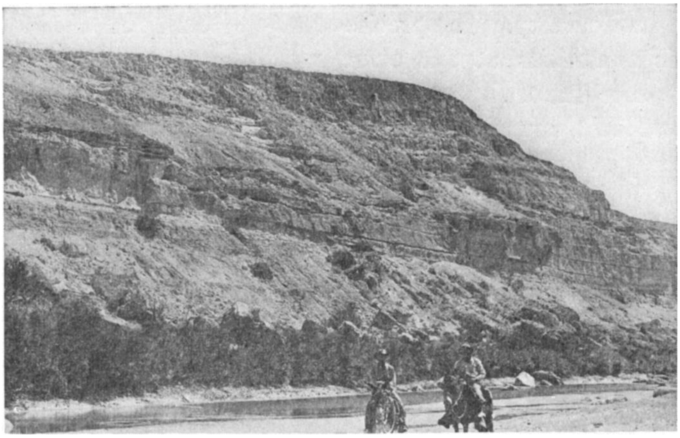

FIG. 18.—Yellow beds and overlying Mesa sandstone on the Arroyo de la Purisima, ten miles below La Purisima, Baja California. Massive fossiliferous bed near center.

Thin sheets of basalt are included in the yellow beds in the lower part of the canyons of the Arroyo San Raimondi and the Arroyo Caije. The relations of the old lava flows are well exposed just south of Caije and along the west side of San Juanico Bay, 7 miles due west of La Purisima. The exposure near Caije is due to a low dome, and here the lava is overlain by a 30-foot, soft, gray sandstone, a local member of the yellow beds. A thin sheet of basalt caps the yellow beds at Purisima Vieja, as shown in Figure 16, and halfway between that place and Poza Honda an igneous mass occupying the bottom of the valley was probably a vent from which this sheet was erupted.

Fossils.—The yellow beds contain fossils at various places which indicate later Miocene age, Carrizo Creek horizon. Possibly the sediments represent a still longer epoch. Fossils collected from the prominent limestone bluff at the head of tidewater at the mouth of the Arroyo de la Purisima were determined as follows by Dr. Julia A. Gardner, of the United States Geological Survey: *Scutella gabbi* Remond: *Terebra* sp., cf. *T. simplex* Carpenter; *Conus* sp., cf. *C. vittatus* Hwass; *Oliva* sp. aff. *O. angulata* Lamarck; *Oliva* n.sp. aff. *venulate* Lamarck; *Phos.* sp.; *Turritella* sp., cf. *T. cooperi* Carpenter; *Turritella* n.sp., cf. *T. ocoyana* Conrad; *Turritella* n.sp. aff. *T. goniostoma* Valenciennes; *Turritella* sp., cf. *T. ineziana* Conrad; *Cancellaria* n.sp., cf. *C. vetusta* Gabb; *Macron merriami* Gabb?; *Natica pablonesis* Clark?; *Chlorostoma* (*Omphalius*) sp.

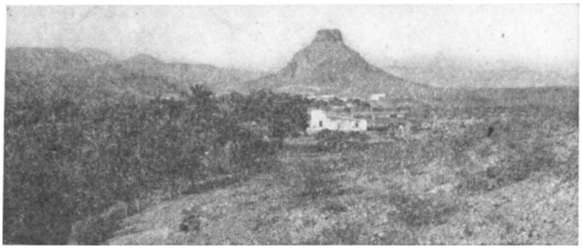

FIG. 19.—La Purisima from the south. Pilon in center is Mesa sandstone capped by basalt; slopes of yellow beds below. Lava-capped mesas in the distance.

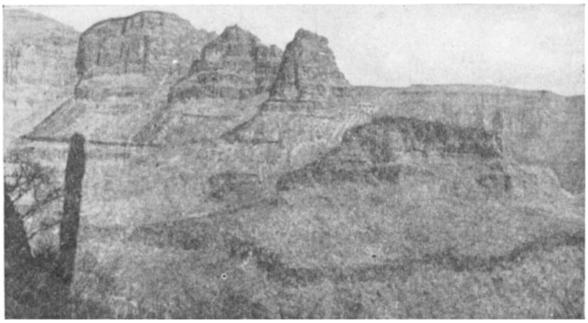

FIG. 20.—Conglomerates, agglomerates, tuffs, and igneous flows near San Miguel, fifty miles northeast of La Purisima, Baja California.

aff. *C. dalli* Arnold; *Glycimeris* n.sp. (2); *Arca* n.sp., cf. *A. samuloensis* Osmont; *Arca* sp. ind.; *Ostrea veatchii* Gabb; *Pecten* (Pecten) *carrizoensis* Arnold; *Pecten* (*Lyropecten*) *crassicardo* Conrad; *Pecten* n.sp. A.; *Cardium* sp.; *Phacoides* sp.; *Mytilus trampaensis* Clark?; *Chione* sp. *Chione* sp., cf. *diabolensis* Clark; *Semele* n.sp. and *Balanus concavus* Brönn. The relations of this limestone are shown in the sections of Figures 1 and 2. Apparently it is at the base of the formation, and the same bed appears again along the arroyo a mile above the 1,360-foot bore hole and outcrops almost continuously to beyond La Purisima. In the vicinity of the latter place Dr. Kew collected the following fossils, determined by Dr. Julia A. Gardner, of the United States Geological Survey: *Strombus* n.sp.; *Turritella* n.sp.; *T.* n.sp., cf. *T. ocoyana* Conrad; *T.* sp., cf. *T. margaritana* Normand; *Calyptraea costellata* Conrad?; *Arca* sp. *Ostrea* sp. ind. *Pecten* n.sp.; *Venericardia* sp., cf. *V. californica* Dall; *Chione* sp. *Chione* n.sp.: *Balanus concavus* Brönn—a Carrizo Creek fauna.

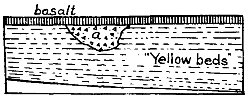

FIG. 21.—Section in east wall of canyon of the Arroyo de la Vaca, showing relations of agglomerate in the yellow beds.

The higher limy member occurring in a thick ledge near the middle of the yellow beds along the walls of the Big Bend and for some distance above it along the Arroyo de la Purisima, as shown in Figures 17 and 18, contain many fossils. A large collection was made from this horizon, but it has been misplaced in the National Museum in Washington. The basal limestone of the yellow beds outcropping in the bed of the Arroyo San Gregorio near Purisima Vieja yielded the following forms: *Purpura*, cf. *P. vaquerosensis* Arnold var.; *Turritella*, cf. *T. ocoyana* Conrad; *T.*, cf. *T. ineziana* Conrad; *T.*, cf. *T. margaritana* Normand; *Arca* sp. ind. *Pecten* sp., cf. *P. estrellanus* Conrad; *Pecten crassicardo* Conrad; *Pecten* sp., cf. *Pecten* n.sp., *Cytherea* n.sp. ind.—a Carrizo Creek fauna.

Only a few fossils were found in the extensive exposures of yellow beds north of the Arroyo Valle, 45 miles northwest of La Purisima. In a lower sandy member are abundant *Ostrea bourgeosii* Gabb and *Turritella*, cf. *T. jewetti*. At another place were collected, from the middle beds, *Chione*, cf. *C. elsmerensis* English and many specimens of *Tellina*, cf. *T. ocoides* Gabb. These fossils were determined by Dr. Julia A. Gardner, who regards them as probably Upper Miocene.

Fossils collected near the top of Cerro Angel, 18 miles west of San Ignacio, were identified as follows: *Oliva* sp.; *Turritella*, cf. *hoffmani* Gabb; *Calyptraea*, cf. *diegoana* Conrad; *Glycymeris* sp.; *Arca* sp.; *Pecten* n.sp.; *Pecten* sp.; *Dosiniaarnoldi* Clark; *Chione elsmerensis* English?; *Chione* sp.; and *Macoma vaulecki* Arnold. They are regarded as San Pablo or late Miocene.

These yellow beds outcrop extensively under the lava mesas about San Ignacio (see Fig. 14) and in the arroyo below that village. Fossil oysters are abundant in some of the layers.

Yellow beds similar to those of the La Purisima region overlie Monterey beds in the slopes east of Rancho Tepetate. The steeply uplifted strata just northwest of Rancho Platana include a richly fossiliferous limy ledge which yielded fossils of the same fauna as those occurring in the basal limestone member of the yellow beds in the Arroyo de la Purisima. The following were identified by Dr. Julia A. Gardner: *Strombos* n.sp. (same as one at La Purisima); *Turritella* n.sp. 1 and 2; *Codakia* sp.; *Cardium* sp. ind.; *chione* sp., cf. *C. fernandoensis* English; *C.* sp. ind. and *Psephidea?* sp.—a Carrizo Creek fauna. It is reported that later Miocene beds outcrop on the gulf shore near Cayote Point and Agua Verde Bay, doubtless coming up from under the agglomerate series, as shown in section 4.

From a bed in the base of the formation or not far below it, 8 miles northwest of El Pilon, were collected the following fossils: *Turritella* sp., cf. *T. margaritana* Normand; *Turritella* N. sp.; *Yoldia* sp.; *Ostrea* sp. ind.; *Mytilus?* sp.; *Modiolus?* sp.; *Pecten?* sp., *Chione* sp., cf. *C. fernandoensis* English and *Mactra?* sp.; determined by Dr. Julia A. Gardner who regards them as late Miocene or early Pliocene.

MESA SANDSTONE AND THE GREAT LATER TERTIARY VOLCANIC SERIES

Gabb recognized the fact that the widespread mesas of southern Baja California consist of a thick mass of west-dipping sediments and conglomerates. He named it the "mesa sandstone," and while he erroneously extended the application of the name to other formations constituting mesas in the central and northern parts of the peninsula, the name may be useful in the southern part of the region until a more definite classification is practicable. I find that the formation presents two phases: a massive, gray sandstone, several hundred feet thick in the western portion of the mesa region, rapidly merging into conglomerates with thick bodies of agglomerate and tuff to the east. This relation is shown in sections 11–20, Figures 3 and 4, and is a most striking feature. The coarse sediments are in hard, massive beds, 4,000 feet thick in places, constituting the high sierra extending continuously southward from near latitude 28° to beyond La Paz. Sheets of contemporaneous igneous rocks are included and the succession is penetrated by many intrusions, notably in the Mulegé and Santa Rosalia regions. To the east it lies on schist, granite, etc., and to the west on sandstone of earlier Tertiary age. South of the latitude of La Paz the thickness diminishes, volcanic rocks are not present, and at Todos Santos the underlying rocks reach the shore of the Pacific Ocean. I did not observe its relations north of latitude 28°.

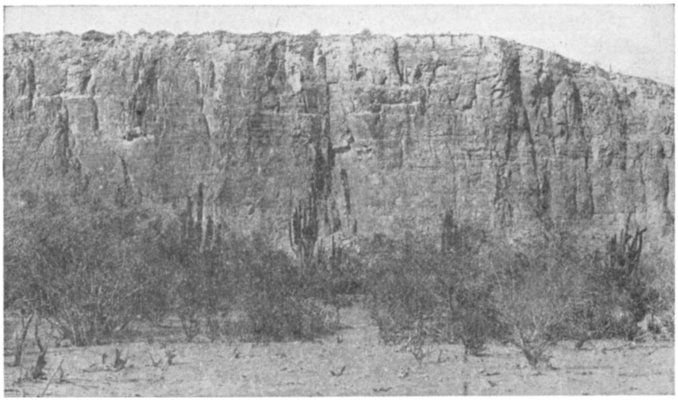

FIG. 22.—Mesa sandstone on the Arroyo San Andres, twenty-one miles south of Comondu, Baja California. Shows massive bedding.

In the area of the great, lava-covered mesas extending along the Pacific slope past San Ignacio, La Purisima, and Comondu, the yellow beds are overlain by massive, gray, mesa sandstone. This sandstone is conspicuous in the walls of many canyons which cut the mesa zone, notably in the arroyos San Raimondi (or Miguel), San Gregorio, De la Purisima, Comondu, San Benancio, San Andres, and Santo Domingo. The greatest thickness observed in this area is 300 feet; to the west the beds are thin out to nothing under the lava caps of the mesas, and to the east they merge into the great formation of detrital and volcanic rocks constituting the central sierra. This transition is well exposed in the Arroyo San Raimondi near the little pueblo of San Miguel, in the canyon of the Arroyo San Gregorio above Purisima Vieja, in the Arroyo de la Purisima above Huerta Vieja (a few miles above La Purisima), and it is also evident in the canyons from the Arroyo Comondu southward. The change to the east consists in the sediments becoming coarser and thicker, and probably overlying beds also are present under the great sheets of the basalt which cover the high mesas. Close scrutiny would probably reveal the presence of several formations in the sandstone series. A feature of this kind is clearly apparent about La Purisima where a harder, massive sandstone appears as a huge wedge in the other sediments (see Fig. 17). It thins out to the southwest, a mile or two below La Purisima.

The eastern extension of the mesa sandstone was not studied in detail, but was observed in various trips across the high sierra. The predominating rock is conglomerate in thick beds and consisting largely of bowlders of igneous rocks together with some quartzite. Sheets of lava, layers of tuff, and thick bodies of agglomerate are included. Some of the lavas are basalt, others are light-colored, more acidic rocks. To the east many intrusive masses are present. These are conspicuous west of Santa Rosalia, near Mulegé, east of Conception Bay, and southward past Loreto.

A fine exposure of mesa sandstone on the west bank of the Arroyo San Gregorio, 10 miles slightly north by west of La Purisima, shows the following strata:

	Feet
Lava sheet at top of mesa	00+
Sandstone, gray, massive, compact	60
Sandstone, white, soft	120
Bowlders and sand	40
Agglomerate, reddish in places	4
Yellow beds in bottom of the arroyo	30

Near Purisima Vieja, on the Arroyo San Gregorio, 12 miles northwest of La Purisima, a thin lava bed lies at the base of the formation (or in the top of the yellow beds, see Fig. 16), and a short distance above that place is a vent from which this lava flow probably came. Near San José, 7 miles farther up the same canyon, conglomerates predominate in the high canyon walls and two sheets of basalt are included. The later are well exposed in Arroyo Caije near Rancho Nombre de Marie, 25 miles south-south west of Mulegé. In the extensive exposures of the agglomerates and conglomerates near San Miguel on the Arroyo Raimondi (or Miguel), as shown in Figures 15 and 20, a thin sheet of trachyte is included in the succession. Near Rancho los Angeles in the same canyon the cliffs 500 feet high consist of coarse conglomerate, some beds being harder than others and consisting largely of bowlders of igneous rocks in gray sand. Below Rancho Mescal, a few miles above Rancho las Tules, underlying gray sandstone appears lying in yellow beds and in places on agglomerate which displaces the upper members of the yellow beds. These features are also well exposed halfway between Rancho las Tules and Rancho San Antonio. Not far below the latter place the basalt beds of the mesa sandstone thin out and the lava of the mesas lies directly on top of the yellow beds. The relations in this arroyo are shown in Figure 15.

Mesa sandstone appears at San Vicente, a ranch 5 miles southeast of La Purisima, where a fine spring issues from it, and is well exposed along the arroyos San Antonio and Pabellon 10–20 miles south of La Purisima. In the latter there are high bluffs of it at Rancho Pabellon and extending to beyond Coyote hole a watering-place as head of tidewater, 20 miles south-southwest of La Purisima. Here the rock is soft sandstone, in part pale greenish and yellowish. It is capped by caliche and conglomerate of Quaternary age which covers the adjoining mesas. The yellow tint may be due to a mixture of detritus from yellow beds which do not outcrop in this vicinity.

In the deep canyon of the Arroyo Comondu, near the village of Comondu, there are high walls of mesa sandstone capped by basalt of the lava sheets which cover the adjoining mesas, and there is also a cap of basalt at lower level, apparently a remnant of a sheet which flowed down the canyon when it had only about half its present depth. It is possible, however, that this lava sheet is included in the mesa sandstone, for such a relation is shown on the south side of the canyon 12 miles below Comondu, just above the mouth of the Arroyo Belamote. In that vicinity also there are some conglomerate members showing strong unconformity at base, and a few conglomeratic layers are included in the gray sandstone. It is probable that the mesa-sandstone outcrop extends down the Arroyo Comondu to Rancho San Andreta, near the mouth of the arroyo, where the following section is exposed:

Conglomerate	30 feet, many fossils
Gray sand, pale greenish tint	20 feet
Limy ledge, yellowish	5 feet exposed

Fossils collected from the basal bed in this exposure were determined by Dr. Gardner as *Turritella*, *Cytherea* and *Balanus* ?, and a *Chione* resembling *C. elsmerensis* English, probably Pliocene in age. This is the only paleontologic evidence that I obtained as to the age of the formation and it is not conclusive.

Extensive exposures of mesa sandstone are presented in the Arroyo San Benancio and the Arroyo San Andres south of Comondu, one of which is shown in Figure 22. The sandstone, conglomerate, agglomerate, tuff, etc., constitute cliffs and high canyon walls along the west side of the Gulf of California from Agua Verde Bay to Canyon de los Reyes. A section in the latter shows the following features:

GENERALIZED SECTION OF STRATA IN CANYON DE LOS REYES

	Feet
Soft, gray sandstones, some beds conglomeratic (top of ridge)	220
Rhyolite flow (bench-maker)	40
Soft, gray sandstone, several beds of conglomerate to the east	260
Conglomerate with bowlders of igneous and other crystalline rocks	40
Rhyolite flow (making wide bench)	30–70
Gray conglomeratic sandstone with agglomerate layers	200
Agglomerate, tuff, volcanic ash, igneous sheets. Bedding massive extends to tide-level	650
Total thickness	1,650

The thin sheets of rhyolite included in this section thin out to the south, but thicken considerably to the north, and the mass of agglomerate also thickens greatly in that direction. This series appears again in ridges passing just east of La Paz and on the islands of Espiritu Santo, Partida, and San Josef, where it consists of thick bodies of agglomerate, tuff, and eruptive rocks. The thinning and fining of the formation to the west is plainly visible in many canyons on the west slope of the sierra west and northwest of La Paz as far north as the Arroyo Santa Cruz near latitude 25° 20′. In this part of the peninsula the soft, gray, massive, typical "mesa sandstone" appears extensively in the highlands of the sierra as a component of the complex; but to the west, as the beds thin and fine, it becomes the dominant feature. It is exposed in the arroyos Conejo, Datilar, Guadalupe, 35–60 miles west of La Paz, and in the cliffs just below San Hilario; but at all of these places layers of pebbles are included and scattered bowlders occur. About El Pilon, 10 miles north of Hilario, it appears in many cliffs, some of which show limy layers. Farther north the conglomerate admixture increases notably in the vicinity of Rancho Jesus Maria, 35 miles north-northwest; but at the north side of Cerro Nombre del Dios, 6 miles southwest of that ranch, the gray sandstone contains only a few thin beds of conglomerate and widely separated bowlders. The westernmost exposure observed in this portion of the peninsula was on the Arroyo San Luis, 17 miles northwest of San Luis, where the sandstone is fine-grained and massive.

PLIOCENE TO POST-PLIOCENE

Along the wide belt of lower lands adjoining the Pacific south of latitude 26° 30′, there is a cover of sand and gravel with limestone members which doubtless include not only the Quaternary, but probably also a formation of Pliocene age. These deposits vary in thickness from a few feet to 200 feet or more, and they extend far up the slopes, and on the higher mesas they are probably represented by a thick cap of bowlders. The latter are especially well exhibited on the high mesas north and northeast of San Hilario and on the long sloping mesas crossed by the main trail north from San Luis. The wide, low plains of the Magdalena region are covered by a deposit of sand of Quaternary age which to the south extends to the Arroyo Salado and beyond, and some distance up the slopes to the east. At Aqua Verde near Rancho Salado (latitude 24° 31′, longitude 111° 31′), underlying yellow sands with hard, limy ledges appear in a cliff 40 feet high. The section at this place is as follows:

	Feet
Gray conglomerate sandstone, which floors the adjoining low sloping mesa	15
Yellow, fine-grained sandstone somewhat harder beds above, and at base a wedge-shaped, hard, limy ledge with fossils	25

The fossils collected here were determined by Dr. Julia A. Gardner as follows: *Turritella* sp.; *Arca* aff. *A. microdonta* Conrad; *Mytilus* sp.; *Modiolus* sp.; *Periploma* (*Halistrepta*) *sulcata*, Dall?; *Tivela* n.sp.; *Chione latilamenosa*, A and M? *C.* sp.; *Metis* aff. *M. alta* Conrad and *Balanus* sp. "Age post-Miocene."

These yellowish beds extend for 3 or 4 miles up the Arroyo Salado and lie on the Eocene (?) sandstone. Probably their yellow color is due to material from the Monterey formation or yellow beds underlying them. They extend up the adjoining plateaus to an altitude of 500 feet or higher. Limestones of this formation are conspicuous in the Cerrito Flor de Melba, 60 miles west of La Paz, and on the walls of various arroyos from Datilar to Cuaño, as well as in cliffs along the ocean (60–40 miles west of La Paz). These limestones occur at several horizons, and they are highly fossiliferous at most places, but the fossils of the upper beds at least appear to be post-Pliocene. The dip is to the southwest at a low angle, and the beds extend far up the west slope of the sierra where they overlie the mesa sandstone.

THE GREAT UPLIFT

It has been found that much of the peninsula of Baja California has been uplifted out of the sea in very recent geologic times. Deposits of modern sea shells occur at many places in regions up to altitudes of 1,000 feet and they are reported as high as 3,300 feet. Old belts of sand dunes and shore lines are conspicuous far above sea-level in several areas. Wittich[1] has presented many interesting facts relating to this subject with illustrations of shell deposits and shore features up to altitudes of 1,052 meters in a divide near Mission San Borja; this was as high as he ascended in his explorations.

The emergence has occupied a somewhat long time and may still be in progress. The shore erosion has been effected at various stages, although some of it may have been developed during the preceding submergence. The latter was apparently relatively transient, and most of the present configuration of the land was developed prior to this event.

[1] Ernesto Wittich, "La Emersion Moderna de la Costa Occidental de la Baja California," *Soc. Cien. Antonio Alzate (Mexico) Memoirs*, Vol. XXXV, pp. 121–44.